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AN ASSESSMENT OF THE USEFULNESS OF SOME SNOW PREDICTORS

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Summary. The probability of snow is obtained for different values of four predictors, based on observations made at 11 stations in the Gloucester group. The predictors are (a) the 1000–850-mb adjusted thickness, (b) the height of the dry-bulb freezing level, (c) the height of the wet-bulb freezing level, and (d) the 1000–900-mb adjusted thickness. The probabilities obtained for predictors (a) and (b) are compared with those given by Boyden. The success obtained at the Gloucester group stations in forecasting predictors (a), (b) and (c) is indicated and the effect of the forecasting errors on the performance of each predictor is assessed. Similarly, the success obtained by the 10-level atmospheric model on a fine mesh in forecasting predictor (d) is indicated together with the effect of the associated forecasting errors on the performance of this predictor. The comparative efficiency of the predictors in forecasting snow is assessed. A method is given for adjusting the 1000–900-mb thickness to allow for surface pressure and station height.

Introduction. Figure 1 shows the locations, indicated by solid circles, of 11 stations in the Gloucester group which took part in an investigation into the usefulness of various snow predictors during the winters of 1966–67, 1967–68 and 1969–70. The predictors were (a) the 1000–850-mb thickness, adjusted for sea-level pressure and station height as described by Boyden,[1] (b) the height of the dry-bulb freezing level above the station and (c) the height of the wet-bulb freezing level above the station. Values of all three predictors were estimated for each station for 00 GMT and 12 GMT. If precipitation of any type was observed within 6 hours either side of these times, the values and the precipitation type were extracted for discrimination analysis. If, however, more than one type of precipitation occurred during a period, then the period was excluded unless it was clear that one type was more closely associated with the middle of the period than the other(s). Forecast values of the three predictors 12 hours ahead from 00 GMT and 12 GMT were also obtained for seven of the 11 stations. The observations of precipitation type and the actual and forecast values of the predictors were obtained as a daily routine. Six of the stations were subsidiaries, observing at hourly intervals, and five, mainly the high-level stations, were auxiliaries, observing at 3-hourly intervals. The auxiliary stations provided observations of precipitation type only, the actual and forecast values of the three predictors for these stations being obtained by some of the subsidiary stations and the main meteorological office at Gloucester.

(*Note:* throughout the investigation, observations of drizzle were treated as rain.)

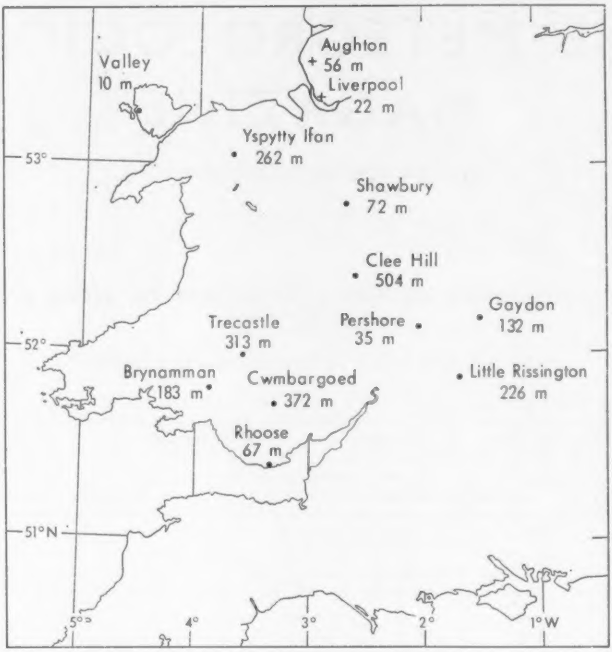

FIGURE 1—LOCATION OF STATIONS

The object of the investigation was primarily to find values of the three predictors associated with various probabilities of precipitation being in the form of snow over hilly terrain, and to find out whether, for the first two predictors, these values differ in any systematic way from those given by Boyden.[1] (The comparison cannot be made for the wet-bulb freezing level since Boyden did not assess this predictor, having deduced that humidity is usually unimportant in considering the probability that snow will melt. On the other hand, other writers such as Lumb[2] have stressed the importance of the wet-bulb freezing level as a snow predictor.) Secondly, the aim was to investigate the success obtainable in forecasting the values of the predictors, the effect of forecast errors on their performance, and to determine whether any improvements to the forecasting techniques could be suggested in the light of added experience. Because of the relatively small number of occasions of moderate to heavy snow of any duration it was decided to include all reported occasions of snow in the investigation. Furthermore, since a good deal of the wintry precipitation over the high ground of Wales is showery in character, it was decided to distinguish between showery and non-showery precipitation. The number of snow occasions, including both showery and non-showery, ranged from 108 at Yspytty Ifan to 28 at each of the three lowest stations Rhoose, Pershore and Valley. Overall, the precipitation occasions totalled 579 of snow, 101 of sleet and more than 1400 of rain. By use of the same basic data, the investigation was

later extended to include an assessment of the 1000–900-mb thickness, adjusted for sea-level pressure and station height as indicated on page 355, as a snow predictor.

The 1000–850-mb adjusted thickness as a predictor. Figure 2 shows the probability of rain, sleet* and snow for various values of the 1000–850-mb adjusted thickness for occasions of non-showery precipitation. The probabilities are based on the nine inland stations, Clee Hill, Cwmbargoed, Trecastle, Yspytty Ifan, Little Rissington, Brynamman, Gaydon, Shawbury and Pershore. The two coastal stations Valley and Rhoose are not included since it is thought likely that different criteria would apply to these stations. The curves were drawn to give a smooth fit to the points which had themselves been subjected to smoothing. This smoothing was carried out by taking 5-term running means of the percentage frequency of occurrence of each of the three categories over 1-gpm bands of the adjusted 1000–850-mb thickness. The results were plotted at the mid point of the 5-gpm thickness range. The pecked line shows the effect on the snow probability of the errors made by the Gloucester group of stations in forecasting the thickness 12 hours ahead (see pages 352–353). Probability curves were drawn in the same way for occasions of showery precipitation.

Table I shows that the corresponding values for non-showery and showery precipitation are in close agreement and 'Student's' *t*-tests indicate that all the apparent differences could readily arise by accident of sampling.

The critical values obtained by Boyden[1] which were based on observations from all the radiosonde stations in the British Isles are also shown. The Boyden figures are not strictly comparable because when computing the probabilities of snow he counted an occurrence of sleet as half to snow and half to rain.

TABLE I—VALUES OF THE 1000–850-mb ADJUSTED THICKNESS IN GEOPOTENTIAL METRES CORRESPONDING TO DIFFERENT PROBABILITIES OF SNOW, DISTINGUISHING BETWEEN NON-SHOWERY AND SHOWERY PRECIPITATION (NOT TAKING INTO ACCOUNT THE EFFECT OF FORECAST ERRORS BUT INCLUDING THE EFFECT OF ERRORS IN ESTIMATING THE BASIC THICKNESS DATA)

	Percentage probability of snow				
	90	70	50	30	10
			geopotential metres		
1000–850-mb adjusted thickness for non-showery precipitation	1282 (1283)	1289 (1291)	1293 (1294)	1296 (1298)	1301 (1303)
1000–850-mb adjusted thickness for showery precipitation	1281 (1283)	1290 (1291)	1293 (1294)	1295 (1297)	1299 (1301)
1000–850-mb adjusted thickness (Boyden)	1281	1290	1293	1298	1303

Notes: (a) Values adjusted to make them comparable with those obtained by Boyden are shown in brackets.

(b) A change of 1 gpm in the 1000–850-mb thickness corresponds to a change of 0·21 degC in the mean temperature of the layer.

* The term sleet is commonly used in this country to describe precipitation of snow and rain (or drizzle) together, or of snow melting as it falls, but it has no agreed international meaning.

The values shown in brackets are those for the present investigation adjusted to make them comparable with the Boyden values from which they differ on average by less than 1 gpm. 'Student's' *t*-tests again indicate that all the apparent differences could readily arise by accident of sampling. The close agreement with Boyden's values is a little surprising because Boyden used instantaneous and simultaneous values as observed at radiosonde stations, whereas for the present investigation, results are based on a relationship between precipitation in a 12-hour period and estimated values of the predictor. Thus the errors in the basic data of the present investigation should be greater than those in Boyden's data. The effect of unbiased errors on the probability curves should be to degrade the apparent performance relative to the optimum performance in a similar way to that in which errors in forecasting the predictor degrade the apparent performance (see pages 352–353). Consequently, relative to the optimum performance of the predictor, the probability values in both investigations should already be changed in the same directions as those shown in Figure 2 for the effect of forecasting errors relative to the apparent probability

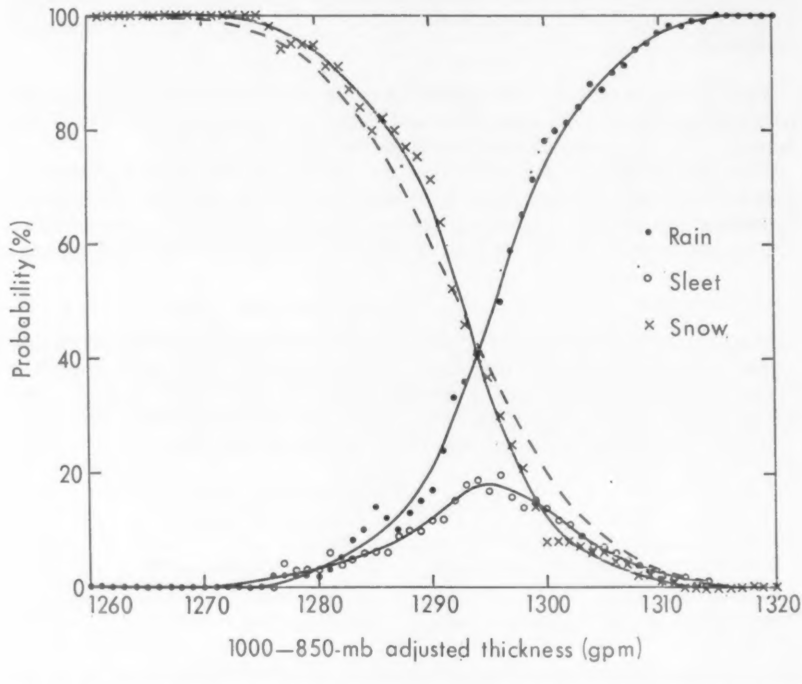

FIGURE 2—PROBABILITY OF RAIN, SLEET AND SNOW FOR VARIOUS VALUES OF THE 1000–850-mb ADJUSTED THICKNESS

The curves are based on occasions of non-showery precipitation at nine inland stations. The pecked line shows the effect on the snow probability of errors in 12-hour forecasts of the thickness made by the Gloucester group of stations.

values. This degradation of performance should be greater for the present investigation than for Boyden's. The effect should be small for the 50 per cent values, tend to lower the apparent thickness for the high probabilities and tend to increase them for low probabilities. Perhaps the close agreement with Boyden's results indicates that the errors involved in estimating the thickness were small.

Probability curves were also prepared for non-showery and showery precipitation combined, but a distinction was drawn between the four highest and five lowest inland stations. Only small, non-significant differences emerged. This indicates that the Boyden correction technique for adjusting the 1000–850-mb thickness for station height works satisfactorily. Similar studies were carried out for the other predictors. For the 1000–900-mb adjusted thickness the differences were again not significant but for the two freezing levels the results were inconclusive.

For non-showery and showery precipitation combined, if snow is forecast when the 1000–850-mb adjusted thickness is correctly forecast as 1293 gpm or less (1293 gpm being the thickness corresponding to a 50 per cent probability of snow) the percentages of successful forecasts for each of the nine inland stations range from 75 to 90 per cent and the successful forecasts represent 80 to 90 per cent of the total snow occasions at each station. For the two coastal stations, Rhoose and Valley, the percentages of successful forecasts are lower, ranging from 60 to 65 per cent, representing 80 per cent of the total snow occasions at both stations. This reduced success is not unexpected at these stations where the warming effect of the sea may turn snow into sleet at critical temperatures. Because of the small sample of data for Rhoose and Valley alone, it is not possible to obtain realistic probability curves for these stations. However, the data suggest that the critical value below which rain is unlikely is about 1290 gpm. Sleet was reported at Rhoose in non-showery situations with thickness values as low as 1280 gpm.

The height of the dry-bulb freezing level above the station as a predictor. Figure 3 shows the probability of rain, sleet and snow for various values of the height of the dry-bulb freezing level above the station for occasions of non-showery precipitation. The probabilities are based on the nine inland stations. The curves were drawn to give a smooth fit to the points which had themselves been subjected to smoothing. This smoothing was carried out by taking 11-term running means of the percentage frequency of occurrence of each of the three categories over 1-mb bands of the height of the freezing level. The results were plotted at the mid point of the 11-mb height range. However, this smoothing technique was not adequate for freezing levels below 6 mb because the occasions recorded as 'zero', which represented a large proportion (about 50 per cent) of the snow occurrences, included many associated with negative surface temperatures. On most of these 'zero' occasions, representative heights for the freezing level would have been negative. In the absence of detailed information, various methods of using the data to define the snow probability curve in the 80 to 100 per cent region were tried, including progressively reducing the smoothing interval and also using skew intervals. Each method resulted in obvious discontinuities and was unsatisfactory. In the circumstances, Little Rissington, whose data were accessible and whose station height is about midway between the highest and lowest of the nine

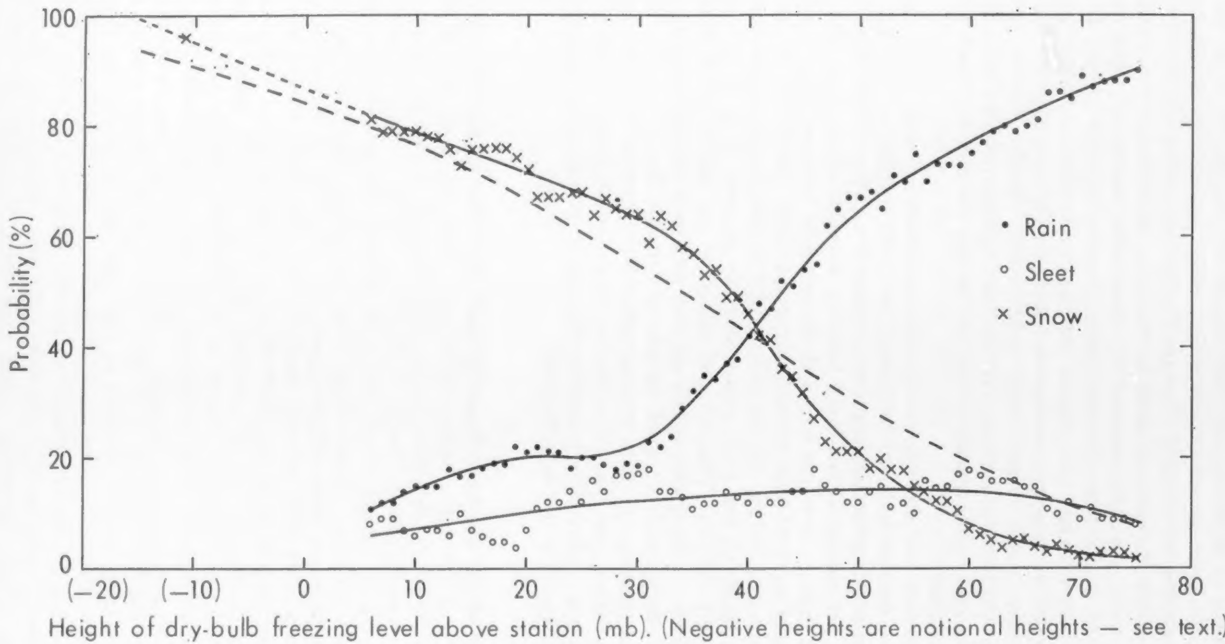

FIGURE 3—PROBABILITY OF RAIN, SLEET AND SNOW FOR VARIOUS VALUES OF THE DRY-BULB FREEZING LEVEL

The curves are based on occasions of non-showery precipitation at nine inland stations. The pecked line shows the effect on the snow probability of errors in 12-hour forecasts of the height made by the Gloucester group of stations obtained for all forecasts; the corresponding line obtained when forecasts associated with freezing-level heights of 'zero' were excluded is almost the same.

inland stations, was chosen for further examination. Surface dry-bulb temperatures were obtained for the 24 occasions when the freezing level was recorded as 'zero'. All but one were snow occasions and the average surface temperature was −0·6°C. Assuming a notional lapse rate below ground similar to that adopted from Figure 1 of Boyden,[1] namely 0·055 degC/mb, this suggests roughly a 96 per cent snow probability at an average notional freezing level of −11 mb. This plot of 96 per cent at −11 mb was then used to extrapolate the snow probability curve in the 80 to 100 per cent region, shown dotted in Figure 3.

The pecked line shows the effect on the snow probability of the errors made by the Gloucester group stations in forecasting the height of the freezing level 12 hours ahead (see pages 352–353). Probability curves were drawn in the same way for showery precipitation.

Table II shows that the corresponding values for showery precipitation tend to differ more for high than for low probability values and are on average 4 mb higher than those for non-showery precipitation which is equivalent to a change in temperature of about 0·2 degC at a level. 'Student's' *t*-test indicates that this apparent difference could readily arise by accident of sampling. The values in brackets are those for the present investigation adjusted to make them comparable with the Boyden values. The corresponding values for both showery and non-showery precipitation are on average 6 mb higher than the Boyden values which is equivalent to a change in temperature of about 0·3 degC at a level. 'Student's' *t*-test indicates that the difference is statistically significant. For the reasons discussed on pages 343–345, the effect of unbiased errors in the data used for the present investigation relative to the errors in the Boyden data would be expected, for the present investigation, to lower the apparent heights for high probabilities and to increase them for low probabilities. This effect cannot therefore account for the differences found in the values for the higher probabilities between the present investigation and that of Boyden.[1] However, the estimates of freezing level for the present investigation relate

TABLE II—VALUES OF THE HEIGHT OF THE DRY-BULB FREEZING LEVEL ABOVE THE STATION IN MILLIBARS CORRESPONDING TO DIFFERENT PROBABILITIES OF SNOW, DISTINGUISHING BETWEEN NON-SHOWERY AND SHOWERY PRECIPITATION (NOT TAKING INTO ACCOUNT THE EFFECT OF FORECAST ERRORS BUT INCLUDING THE EFFECT OF ERRORS IN ESTIMATING THE BASIC DRY-BULB FREEZING-LEVEL DATA)

	Percentage probability of snow				
	90	70	50	30	10
			millibars		
Height of dry-bulb freezing level for non-showery precipitation	−4*	22	38	46	58
	—	(29)	(41)	(49)	(67)
Height of dry-bulb freezing level for showery precipitation	4	30	41	48	58
	—	(38)	(45)	(51)	(63)
Height of dry-bulb freezing level (Boyden)	12	25	35	45	61

Notes: (a) Values adjusted to make them comparable with those obtained by Boyden are shown in brackets. For the 90 per cent probability it was not possible to make this adjustment.

(b) By use of Figure 1 of Boyden[1] a change of freezing level by 1 mb is taken to be equivalent to a change in temperature of 0·055 degC at a level.

* Notional height (see text).

mostly to high-level stations but were based on the network of radiosonde stations which are at relatively low levels. Because low-level air is cooled by ascent over high ground and the height of the freezing level above mean sea level is thereby usually reduced, it is possible that the freezing-level estimates were affected by a small positive bias which could account for the differences between the two investigations.

For non-showery and showery precipitation combined, if snow is forecast when the height of the dry-bulb freezing level above the station is correctly forecast as 40 mb or less (40 mb being the height corresponding to a 50 per cent probability of snow) the percentages of successful forecasts for each of the nine inland stations range from 70 to 90 per cent and the successful forecasts represent 80 to 95 per cent of the total snow occasions at each station. For the two coastal stations, Rhoose and Valley, the percentages of successful forecasts are lower, ranging from 55 to 60 per cent, the successful forecasts representing 85 to 95 per cent of the total snow occasions at each station. However, if a critical value of 30 mb instead of 40 mb is used for Valley, the percentage of snow forecasts correct improves to 75 per cent representing 80 per cent of the total snow occasions at Valley. No such conclusion can be drawn from the data for Rhoose where the forecast failures are mainly associated with non-showery situations, for which rain and sleet are reported on most occasions with heights between 10 mb and 40 mb.

The height of the wet-bulb freezing level above the station as a predictor. Probability curves were drawn, as described in the previous section, based on the height of the wet-bulb freezing level above the station. Figure 4 shows the curves for non-showery precipitation. As with the dry-bulb freezing level, the smoothing technique was not adequate for freezing levels below 6 mb and recourse was again made to surface observations at Little Rissington. Surface wet-bulb temperatures were obtained for the 40 occasions when the freezing level was recorded as 'zero'. All but two were snow occasions and the average surface wet-bulb temperature was −0·7°C, suggesting roughly a 95 per cent probability at an average notional freezing level of −13 mb. This plot of 95 per cent at −13 mb was then used to extrapolate the snow probability curve in the 60 to 100 per cent region, shown dotted in Figure 4. The pecked lines again show the effect of 12-hour forecast errors made by the Gloucester group stations on the snow probabilities (see pages 352–353).

Table III shows that the critical values for showery precipitation are on average 4 mb higher than those for non-showery precipitation which is equivalent to a change in temperature of about 0·2 degC at a level. 'Student's' *t*-test indicates that this apparent difference could readily arise from sampling. A similar result was obtained earlier for probabilities based on the height of the dry-bulb freezing level.

For non-showery and showery precipitation combined, if snow is forecast when the height of the wet-bulb freezing level is correctly forecast as 10 mb or less (10 mb being the height corresponding to a 50 per cent probability of snow) the percentages of successful forecasts for each of the nine inland stations and Valley range from 75 to 85 per cent and the successful forecasts represent 80 to 90 per cent of the total snow occasions at each station. The coastal station Rhoose shows the lowest forecast success of 60 per cent, representing 75 per cent of the total snow occasions at the station.

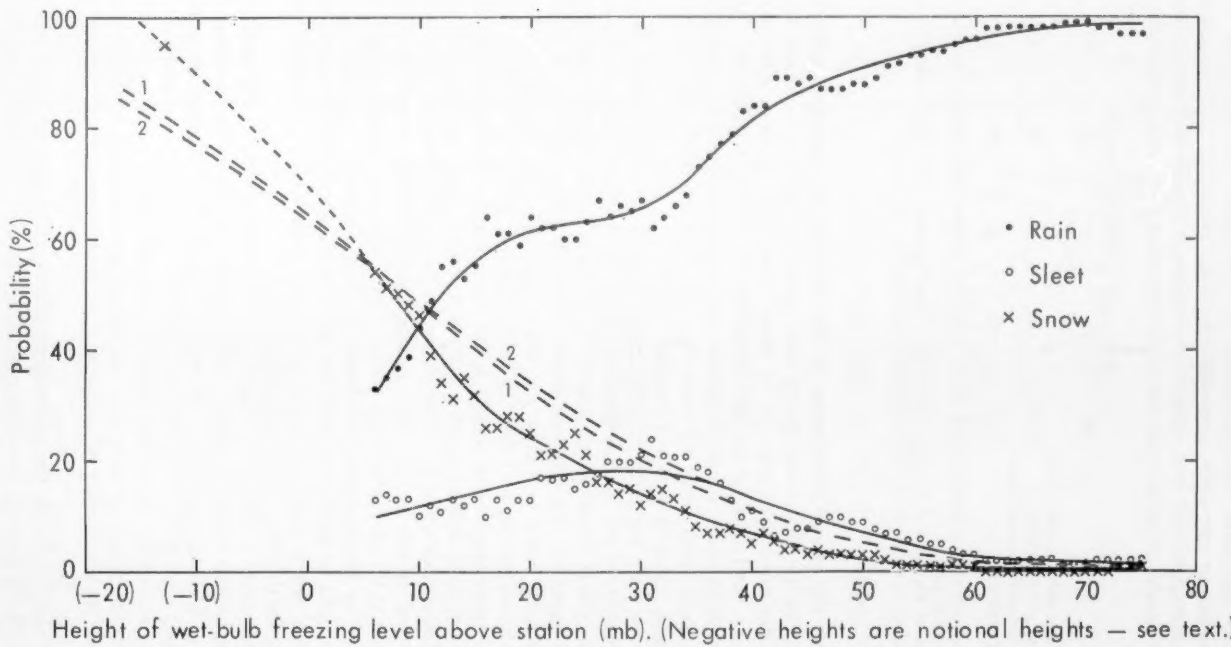

FIGURE 4—PROBABILITY OF RAIN, SLEET AND SNOW FOR VARIOUS VALUES OF THE HEIGHT OF THE WET-BULB FREEZING LEVEL

The curves are based on occasions of non-showery precipitation at nine inland stations. The pecked lines show the effect on the snow probability of errors in 12-hour forecasts of the height made by the Gloucester group obtained (1) for all forecasts and (2) when forecasts associated with freezing-level heights of 'zero' were excluded.

TABLE III—VALUES OF THE HEIGHT OF THE WET-BULB FREEZING LEVEL ABOVE THE STATION IN MILLIBARS CORRESPONDING TO DIFFERENT PROBABILITIES OF SNOW, DISTINGUISHING BETWEEN NON-SHOWERY AND SHOWERY PRECIPITATION (NOT TAKING INTO ACCOUNT THE EFFECT OF FORECAST ERRORS BUT INCLUDING THE EFFECT OF ERRORS IN ESTIMATING THE BASIC WET-BULB FREEZING-LEVEL DATA)

	Percentage probability of snow				
	90	70	50	30	10
			millibars		
Height of the wet-bulb freezing level for non-showery precipitation	−10*	0	7	16	35
Height of the wet-bulb freezing level for showery precipitation	−6*	7	13	20	34

Notes: (a) Boyden did not examine the use of the height of the wet-bulb freezing level as a snow predictor.
(b) By use of Figure 1 of Boyden[1] a change of freezing level by 1 mb is taken to be equivalent to a change in temperature of 0·055 degC at a level.

* Notional height (see text).

Forecasting the three predictors at the Gloucester group stations. The forecasters in the Gloucester group were given a free hand in forecasting the values of the three predictors for 12 hours ahead. In general, advection techniques were used to forecast the 1000–850-mb adjusted thickness. Attempts were made to advect thickness with the surface gradient wind, the 900-mb wind, the 850-mb wind and the 1000–850-mb thermal wind and various fractions of these winds as well as by extrapolation.

Freezing levels were forecast by modifying the upper-air soundings felt to be most representative of the air expected to affect the various stations. At no station were methods found which gave a consistently high degree of success. As was to be expected, the greatest errors occurred during periods of rapid change of air mass when accuracy was most essential. The highest forecast accuracy was found during periods of little change, e.g. February 1968. Table IV shows the percentage of occasions when the error in the forecast of the 1000–850-mb adjusted thickness was 5 gpm or less and 3 gpm or less, and the percentage of occasions when the error in the forecast of the freezing levels was 20 mb or less and 10 mb or less. The standard deviations of normal distributions which would be associated with the average values are shown at the foot of the table. (For the freezing-level forecasts, departures from normal error distributions would be associated with the practice of classifying freezing-level heights as 'zero' when surface temperatures were negative. No attempt was made to allow for this abnormal distribution.)

The average values in this process are simple averages treating each station's results as independent values of equal weight, despite the wide discrepancies in the number of forecasts involved. Alternative methods of averaging might have been used, e.g. by giving weight to stations according to the number of forecasts or by excluding the coastal stations, but the differences between the stations' results are a little greater than would be expected from consideration of the statistical standard error of each result, so simple unweighted averaging was chosen.

At all five inland stations, the percentage of errors less than 20 or 10 mb is less for the dry-bulb freezing level than for the wet-bulb freezing level so that the choice does not affect their relative standing.

TABLE IV—PERCENTAGE SUCCESS IN FORECASTING SNOW PREDICTORS 12 HOURS AHEAD AT STATIONS IN THE GLOUCESTER GROUP DURING THE WINTERS OF 1966–67 AND 1967–68

Station	1000–850-mb adjusted thickness			Dry-bulb freezing level			Wet-bulb freezing level		
	Number of forecasts	Percentage of forecast errors $\leqslant 5$ gpm	Percentage of forecast errors $\leqslant 3$ gpm	Number of forecasts	Percentage of forecast errors $\leqslant 20$ mb	Percentage of forecast errors $\leqslant 10$ mb	Number of forecasts	Percentage of forecast errors $\leqslant 20$ mb	Percentage of forecast errors $\leqslant 10$ mb
Trecastle	466	59	41	504	55	33	501	63	43
Ysptty Ifan	465	59	42	427	54	33	429	61	44
Rissington	89	54	38	87	64	41	87	75	61
Gaydon	143	60	38	52	58	46	61	72	62
Shawbury	39	67	46	39	69	51	39	74	59
Rhoose*	113	64	50	110	63	40	110	54	42
Valley*	85	74	53	76	74	46	76	70	47
All stations	1400	62	44	1295	62	41	1303	67	51
Standard deviation (SD) of error		5·7 gpm	5·2 gpm		22·7 mb (24·0)	18·5 mb (20·5)		21·0 mb (24·0)	14·5 mb (17·5)
Representative SD of error		5·5 gpm			21 mb (22)			18 mb (21)	
Representative SD converted to equivalent temperature units (kelvins)		1·1			1·1 (1·2)			1·0 (1·2)	

* Coastal stations.

Note: Values in brackets show the standard deviation of error when forecasts associated with 'actual' freezing-level heights of 'zero' were excluded.

Because forecasts of freezing levels would be subject to smaller errors when the freezing level is 'zero' than when it is above ground level, the standard deviation of the forecast errors when all forecasts are included should be less than for forecasts when the freezing level is above ground. A separate analysis of forecast errors for the freezing levels was therefore made excluding occasions of 'zero' height. Results of this analysis are shown in brackets in Table IV. They show that the apparent slightly lower standard deviation of error in forecasting the height of the wet-bulb freezing level becomes negligible when 'zero' heights are excluded. There is practically no difference in the accuracy of forecasting the three predictors when the freezing levels are above zero.

The effect of the increased forecast errors in these circumstances would be to further degrade the overall performance of the two freezing-level predictors shown by the pecked lines in Figures 3 and 4. The further degraded performance for the wet-bulb freezing level is shown as a second pecked line in Figure 4, representing an increase in the standard deviation of error from 18 mb to 21 mb. The corresponding line for the dry-bulb freezing level representing an increase in the standard deviation of error from 21 mb to 22 mb is very close to the pecked line in Figure 3 and cannot be distinguished from it.

The effect of forecasting error on predictor performance. Even a predictor which is completely efficient as a snow discriminant, i.e. one for which the probability of snow changes discontinuously from 100 per cent to 0 per cent across some specific value, would be quite useless as a predictor if it could not be forecast with sufficient accuracy. In order to assess a discriminant as a predictor in practice, it is necessary to consider the effect of errors made in forecasting the discriminant on the snow probability curves. To achieve this, the following procedure was used (which implicitly assumes that the errors involved in estimating the data are small in relation to the other errors involved, i.e. in forecasting and the true performance of the predictor):

(a) For each predictor and its associated forecast period, a set of 20 errors was constructed to represent a sample of errors with zero mean and a normal distribution whose standard deviation was the same as that of the errors in forecasting the predictor over the period as shown in Tables IV and V.

(b) The appropriate set of 20 errors constructed in (a) was applied to a selected predictor value to yield 20 predictor values.

(c) For the predictor values determined in (b) the 20 corresponding snow probability values were read from the basic snow probability curve in Figures 2, 3, 4 or 5, as appropriate.

(d) These 20 probability values were averaged to yield the required probability associated with the selected value of the predictor.

(e) Sufficient predictor values were selected to define a curve representing the performance of the predictor under conditions of forecast error, shown as pecked lines in Figures 2 to 5.

(f) When, as for the 1000–850-mb adjusted thickness, the distribution of the snow probability over the range where it was variable could be closely represented by a normal distribution, the standard deviations representing this distribution and that of the appropriate errors of forecasting were simply compounded. The required performance of the predictor under conditions of forecast error was then determined from a

normal distribution with the compound standard deviation and the original mean. The procedures (a) to (e) could have been used throughout but are more cumbersome to operate than (f).

Note that for forecasting purposes it is more realistic to use snow probabilities from the pecked curves in Figures 2 to 5, i.e. curves which allow for the errors of forecasting, rather than from the basic probability curves, and that these differ from Boyden's values. There is, of course, considerable scatter in individual situations.

The 1000–900-mb adjusted thickness as a predictor. Forecasts of the 1000–900-mb thickness are part of the output of the 10-level atmospheric model on a fine mesh.[3] It therefore seemed appropriate to make an assessment of the usefulness of the 1000–900-mb adjusted thickness as a snow predictor, using the same basic data as for the other three predictors and the requisite 1000–900-mb thickness charts which were prepared at Bracknell. The 1000–900-mb thickness values obtained for each station were adjusted as described on page 355. Finally, using the smoothing technique described between pages 343 and 345, probability curves were drawn. Figure 5 shows the curves for non-showery precipitation; the meaning of the pecked lines is given in the following paragraph.

Table V shows the standard of success in forecasting the 1000–900-mb thickness obtained in experiments with the 10-level atmospheric model on a fine mesh.[3] The error was taken to be the difference between the forecast thickness for the grid point at about 51·4°N, 01°W and the corresponding actual value at Crawley (51·1°N, 00·2°W). The standard deviations of normal distributions representative of these forecast errors are shown at the foot of Table V. Although these errors apply to forecasts of the ordinary 1000–900-mb thickness, consideration of equation (3) below and the errors made in forecasts of surface pressure using the model (root-mean-square errors of 2·5 mb for 12 hours and 5 mb for 36 hours) indicates that in practice they also apply to forecasts of the 1000–900-mb adjusted thickness. The effect of the forecast errors on the snow probability was obtained as described between pages 350 and 352. One pecked line on Figure 5 shows the effect of the 12-hour forecast error and the other the effect of the 36-hour forecast error. The effect of the 24-hour forecast error is about midway between that of the 12-hour and 36-hour forecast errors.

TABLE V—PERCENTAGE SUCCESS IN FORECASTING THE 1000–900-mb THICKNESS OBTAINED BY THE 10-LEVEL ATMOSPHERIC MODEL ON A FINE MESH FROM APRIL TO JULY 1973

	12-hour forecast		24-hour forecast		36-hour forecast	
	Percentage of forecast errors					
	$\leqslant$5 gpm	$\leqslant$3 gpm	$\leqslant$5 gpm	$\leqslant$3 gpm	$\leqslant$5 gpm	$\leqslant$3 gpm
Average percentage	75	56	71	51	65	42
Standard deviation (SD) of error (gpm)	4·3	3·9	4·7	4·3	5·4	5·5
Representative SD of error (gpm)	4·1		4·5		5·4	
Representative SD converted to equivalent temperature units (kelvins)	1·3		1·4		1·7	

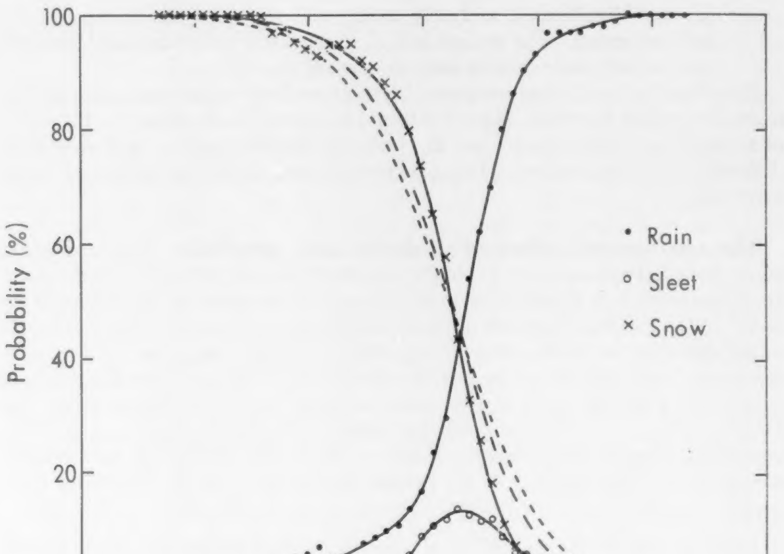

FIGURE 5—PROBABILITY OF RAIN, SLEET AND SNOW FOR VARIOUS VALUES OF THE 1000–900-mb ADJUSTED THICKNESS

The curves are based on occasions of non-showery precipitation at nine inland stations. One pecked line (— — —) shows the effect on the snow probability of errors in experimental 12-hour forecasts of the thickness obtained by use of the 10-level atmospheric model on a fine mesh, and the other pecked line (- - - - -) the effect of errors in the 36-hour forecasts.

Table VI shows that the critical values for showery precipitation are on average 1 gpm higher than those for non-showery precipitation which is equivalent to a change of about 0·3 degC in the mean temperature of the layer. 'Student's' *t*-test indicates that this apparent difference could arise from sampling.

For non-showery and showery precipitation combined, if snow is forecast when the 1000–900-mb adjusted thickness is correctly forecast as 843 gpm or less (843 gpm being the thickness corresponding to a 50 per cent probability of snow) the percentages of successful forecasts for each of the nine inland stations and Valley range from 75 to 85 per cent and the successful forecasts represent 80 to 95 per cent of the total snow occasions at each station. The coastal station Rhoose shows the lowest forecast success of 60 per cent, representing 80 per cent of the total snow occasions at the station. The forecast failures at Rhoose are mainly associated with non-showery situations when sleet is reported with thicknesses as low as 835 gpm.

TABLE VI—VALUES OF THE 1000–900-mb ADJUSTED THICKNESS IN GEOPOTENTIAL METRES CORRESPONDING TO DIFFERENT PROBABILITIES OF SNOW, DISTINGUISHING BETWEEN NON-SHOWERY AND SHOWERY PRECIPITATION (NOT TAKING INTO ACCOUNT THE EFFECT OF FORECAST ERRORS BUT INCLUDING THE EFFECT OF ERRORS IN ESTIMATING THE BASIC THICKNESS DATA)

	Percentage probability of snow				
	90	70	50	30	10
	geopotential metres				
1000–900–mb adjusted thickness for non-showery precipitation	835	841	843	845	847
1000–900–mb adjusted thickness for showery precipitation	835	841	844	846	849

Notes: (a) Boyden did not examine the use of the 1000–900-mb adjusted thickness as a predictor.
(b) A change of 1 gpm in the 1000–900-mb thickness corresponds to a change of 0·32 degC in the mean temperature of the layer.

The adjustment of the 1000–900-mb thickness to allow for surface pressure and station height. Figure 6 shows the relationship between 1000–900-mb thickness and the pressure at the freezing level at Aughton on occasions of sleet at Liverpool Airport. A straight line can be drawn through the points with a slope of 5·7 mb/gpm. At the temperatures involved when sleet occurs, the depth of the atmosphere at low levels corresponding to a pressure difference of 1 mb can be taken as 8 gpm. Then following Boyden's[1] arguments:

Let z in gpm = height of 1000-mb surface above sea level = $z/8$ mb,
Δz = 1000–900-mb thickness,
h in gpm = height of the ground above sea level = $h/8$ mb,
p_g = pressure at the ground in mb, and
p_f = pressure at the freezing level in mb;

then

$$\begin{aligned} p_g - p_f &= (1000 + z/8 - h/8) - p_f \\ &= f(\Delta z) + z/8 - h/8, \end{aligned} \qquad \ldots (1)$$

where the function $f(\Delta z)$ is given by Figure 6 as approximately $5{\cdot}7\ (\Delta z - 834)$. Equation (1) may then be written

$$\frac{p_g - p_f}{5{\cdot}7} + 834 \approx \Delta z + z/46 - h/46 \qquad \ldots (2)$$

$$\approx \Delta z + \frac{p_0 - 1000}{5{\cdot}7} - h/46. \qquad \ldots (3)$$

Of the three terms on the right-hand side of equation (2), $z/46$ is the adjustment to allow for surface pressure, and $h/46$ for the height of the station above sea level. In applying the pressure adjustment over the British Isles it is usually satisfactory to raise the numbering of the 1000–900-mb thickness lines by $(p_0 - 1000)/6$, where p_0 is the general level of sea-level pressure.

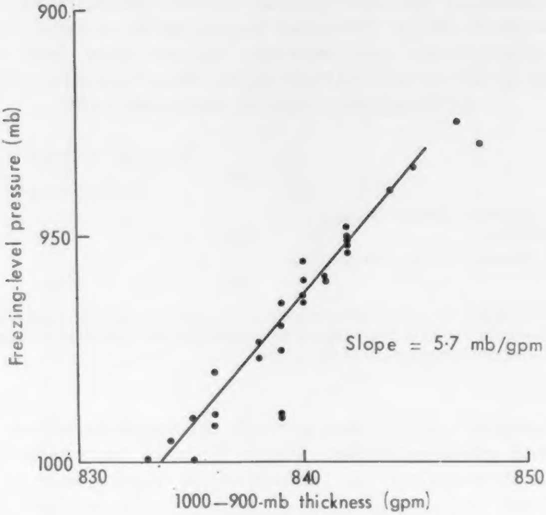

FIGURE 6—RELATIONSHIP BETWEEN THE 1000–900-mb THICKNESS AND THE PRESSURE AT THE FREEZING LEVEL AT AUGHTON ON OCCASIONS OF SLEET AT LIVERPOOL AIRPORT

The comparative efficiency of the predictors in forecasting snow. Apart from difficulties of forecasting, a predictor can be classified as a good one if the range of the predictor through which the probability of one form of precipitation changes from a high to a low value is small. The range through which the probability of snow changes from 70 to 30 per cent was obtained for each predictor from Figures 2 to 5 and converted to an equivalent change in temperature to facilitate comparison.

Table VII shows the range for each predictor obtained from (a) the original snow probabilities and (b) the probabilities allowing for 12-hour forecast errors. In both cases the value for the wet-bulb freezing level is lower than the values for the other three predictors which are not significantly different from one another.

This suggests that the wet-bulb freezing level is the most efficient of the four predictors and that there is no significant difference between the efficiency of the other three.

This result is partly dependent on the method adopted to construct the curve at the higher probability levels for the wet-bulb freezing level as described between pages 345 and 348. However, other methods of construction which were tried, and considerations of the melting of falling snow, similar to those discussed by Boyden,[1] all suggested higher probabilities of snow for low freezing levels than those adopted and a still smaller range through which the probability of snow changes from 70 per cent to 30 per cent for the wet-bulb freezing-level predictor.

TABLE VII—RANGE THROUGH WHICH THE PROBABILITY OF SNOW CHANGES FROM 70 TO 30 PER CENT FOR EACH PREDICTOR, EXPRESSED AS AN EQUIVALENT CHANGE IN TEMPERATURE IN KELVINS

Predictor	1000–850-mb adjusted thickness	Dry-bulb freezing level	Wet-bulb freezing level	1000–900-mb adjusted thickness
			kelvins	
Not allowing for forecast errors	1·4	1·3	0·9	1·3
Allowing for 12-hour forecast errors	2·0	1·8	1·4 (1·5)	2·0
Allowing for 36-hour forecast errors	—	—	—	2·4

Note: The figure in brackets shows the value obtained from the second pecked line in Figure 4 which is based on the standard deviation of forecast errors when forecasts associated with 'actual' wet-bulb freezing-level heights of 'zero' were excluded. The use of this figure would not invalidate the suggestion made below that the wet-bulb freezing level is the most efficient of the four predictors.

Conclusions

(a) For nine inland stations in the region of Wales and the West Midlands, Figures 2, 3 and 4 show the probability of rain, sleet and snow corresponding to different values of (1) the 1000–850-mb adjusted thickness, (2) the height of the dry-bulb freezing level, and (3) the height of the wet-bulb freezing level. The effect on the snow probability of errors in 12-hour forecasts of the predictors made by the Gloucester group of stations is shown for all three predictors.

For the same stations, Figure 5 shows the probability of rain, sleet and snow corresponding to different values of 1000–900-mb adjusted thickness. The effect on the snow probability of errors in experimental 12-hour and 36-hour forecasts of the thickness obtained by use of the 10-level atmospheric model on a fine mesh[3] is indicated.

(b) For all the predictors, the values corresponding to different probabilities of snow are not significantly different for non-showery and showery precipitation. There is also no significant difference between values for the four highest and five lowest inland stations for the thickness predictors, which suggests that the Boyden correction technique for station height works satisfactorily.

For the 1000–850-mb adjusted thickness, the values corresponding to different probabilities of snow are not significantly different from the values obtained by Boyden.[1] For the height of the dry-bulb freezing level, the values are on average 6 mb higher than the values obtained by Boyden. This difference is statistically significant and a possible explanation is suggested.

(*Note:* Boyden did not examine the use of the wet-bulb freezing level or the 1000–900-mb adjusted thickness as snow predictors.)

(c) If snow is forecast at each of the nine inland stations and at the two coastal stations, Rhoose and Valley, whenever the value of a predictor is correctly forecast to be within the range of values corresponding to 50 to 100 per cent probability of snow, the forecast success obtained is relatively low for Rhoose and Valley except when the wet-bulb freezing level or the 1000–900-mb adjusted thickness is used as the predictor for Valley.

(d) The range through which the probability of snow changes from 70 to 30 per cent, used as a measure of the efficiency of the predictors, suggests that the wet-bulb freezing level is the most efficient predictor of snow and that there is no significant difference between the efficiency of the other three.

(e) A series of 12-hour forecasts of (1) the 1000–850-mb adjusted thickness, (2) the height of the dry-bulb freezing level, and (3) the height of the wet-bulb freezing level made by forecasters of the Gloucester group of stations indicated that there is little difference in the accuracy of forecasting the three predictors when freezing levels are above ground level.

(f) Forecasts of the 1000–900-mb thickness are part of the output of the 10-level atmospheric model on a fine mesh[3] and experiments with the model for up to 36 hours ahead show a promising degree of success.

Acknowledgement. The help given by Mr J. Crabtree and Mr C. J. Boyden is gratefully acknowledged.

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A NOTE ON THE VERTICAL DISTRIBUTION OF RAINDROP-SIZE SPECTRA IN TROPICAL STORM FELICE

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Summary. Foil-impactor measurements from tropical storm Felice give raindrop size distributions which are generally in agreement with the classical formula of Marshall and Palmer. Results indicate that there may be significant spectral differences between measurements taken above cloud base and those taken below as predicted by Mason and Ramanadham.

Introduction. On 15 September 1970 two DC-6 aircraft from the Research Flight Facility of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Miami, Florida, carried airborne foil impactors through tropical storm Felice in the Gulf of Mexico. 'A' Flight stayed mostly at 13 000 ft,* well above cloud base, while 'B' Flight stayed at 1500 ft, or about 500 ft below cloud base, while making the measurements discussed in this paper.

The data, raindrop impressions on aluminium foil, were sized and counted from photographs similar to those described by Merceret.[1] These were grouped into sets small enough to represent a sample over a relatively homogeneous region of the storm (2-km path or less) but large enough to satisfy the criterion for statistical significance suggested by Cornford[2,3,4] which here required samples of at least 330 impressions. Data not simultaneously meeting both constraints were discarded.

* 1 ft ≈ 0·305 m.

Droplet impressions were sorted into diameter categories 250 μm wide, the first being those with diameters $\leqslant$ 250 μm, the next being those with diameters $>$ 250 μm but $\leqslant$ 500 μm and so on. From the drop counts in each category values for the liquid water content, mean and median droplet sizes, rainfall rate, and spectral parameters were computed for each set. The spectral parameters were the slopes (λ), intercepts (N_0) and correlation coefficients (r) for least-square fits of the form

$$\ln Nd = \ln N_0 - \lambda D,$$

where $Nd(D)$ is the volume number density (m^{-4}) of droplets of diameter D(cm) as described by Merceret.[5] This form is the same as that used by Marshall and Palmer.[6]

Experimental results. In Felice, the exponential model, though classically applicable at the ground, worked significantly better above the cloud base than below it. Of 92 data sets from 'A' Flight, 85 (92 per cent) showed correlations $r \geqslant 0{\cdot}9$ to the exponential form as did 20 (53 per cent) of 38 sets from 'B' Flight. Since an investigation of the exponential distribution was a major motivation for the overall research programme, subsequent investigation was confined to those data sets satisfying $r \geqslant 0{\cdot}9$. This may have been over-cautious since most of the remainder satisfied $r \geqslant 0{\cdot}75$, but the results, being based on such good fits, may be thus all the more important; even for spectra selected to satisfy $r \geqslant 0{\cdot}9$, the standard deviation of the data about the regression line averaged 1·7 times larger below cloud base than above.

The difference is not accounted for by significant differences in the liquid water content of the environments sampled. The liquid water content above the cloud base averaged 0·935 g/m^3 while below the base it averaged 0·930 g/m^3. On the other hand, not only are the spectra less well correlated to the exponential form below the cloud base, but the intercept of the regression line is quite different. Above the cloud base the intercept N_0 agrees with the classical value within a factor of 3, the mean value being 0·44 of that found by Marshall and Palmer. Below the base the intercept averages 0·095 that of Marshall and Palmer, a factor of 4·61 smaller. Moreover, the mean droplet diameter calculated independently of the least-square fits was 1033 μm above cloud base and 1446 μm below, thus strengthening the inference of a real difference in the spectra in the two regions at the same liquid water content. The possibility of spectral dependence on position with respect to cloud base was predicted in numerical calculations by Mason and Ramanadham[7] and the experimental result is thus particularly interesting.

Conclusion. The mean droplet-diameter data and the intercepts of the Marshall–Palmer regression lines indicate that in tropical storm Felice the smaller raindrops were depleted below the cloud base while the larger ones contributing most heavily to the liquid water content remained little affected. This resulted in a peaked spectrum having a lower correlation with the exponential form. This is in accord with the prediction by Mason and Ramanadham based on the effect of evaporation during the fall of the droplets.

Because Cornford's criteria were satisfied the phenomenon is not likely to be due to sampling errors, and because the phenomenon is so systematic and marked with respect to cloud base it is unlikely to be a fiction of the instrument.

The amount of data is still small, however, and this should be considered more an indicator for further research than a firm conclusion. Analyses of similar flights in future storms should indicate in more detail and with greater certainty the nature and magnitude of the effect suggested here.

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TEMPERATURE DIFFERENCES BETWEEN TWO GROUND-LEVEL SITES AND A ROOF SITE IN SOUTHAMPTON

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Summary. In view of the increasing interest in urban meteorological data and the availability of overlapping records from two Park sites and a roof site in Southampton, it was considered that comparisons of daily maximum and minimum temperatures would be of some interest. The findings of an earlier investigation were confirmed and the final results demonstrated that there was surprisingly little difference between conventional and unconventional site exposures.

Introduction. Temperature observations were made daily at 09 GMT at Southampton East Park climatological station from the mid nineteenth century up to 1969 and are usually quoted as the official climatological values for the district. In 1970 the station was moved to Mayflower Park. In the meantime, continuous temperature records became available in 1962 from the roof of the Weather Centre, situated between the two Park sites on a roughly north–south line and in the heart of the city (see Figure 1 for location of sites).

In 1967, D. M. Love[1] produced a preliminary analysis of the temperature differences between East Park and the Weather Centre roof based on two years' observations, 1963–64. This appeared to show that 'no misleading conclusions would be conveyed by comparison of extreme temperatures recorded on the roof site with the appropriate climatological mean or extreme. Neither does it seem unreasonable to assume that, at times of day other than when the extremes occurred, the temperatures would not show any greater variation between the conventional and unconventional exposures'.

This present assessment arises out of the move of the climatological station to Mayflower Park, to a site which differs greatly from the East Park site. Three full years of observations were available, 1970–72, so the East Park analysis was extended by a third year, 1965, partly to confirm the results from 1963–64, but mainly to establish a three-year period for each survey.

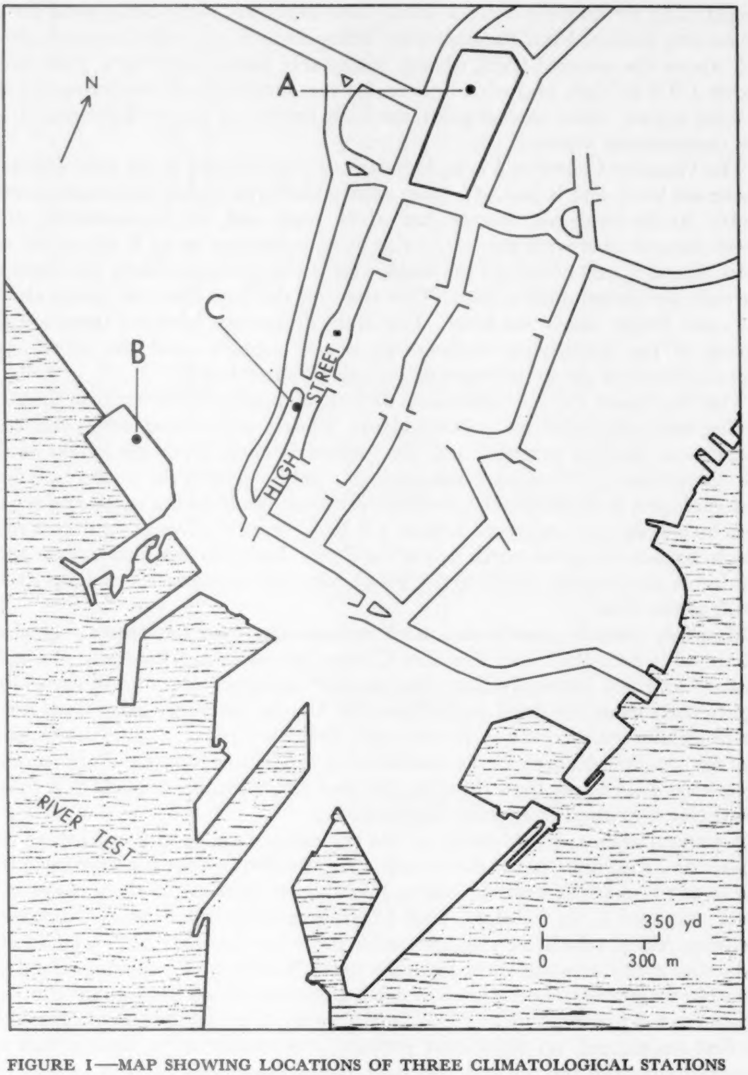

FIGURE 1—MAP SHOWING LOCATIONS OF THREE CLIMATOLOGICAL STATIONS IN SOUTHAMPTON

A East Park. B Mayflower Park. C Weather Centre.

The sites. The East Park and Weather Centre roof sites were described fully in Love's article but a brief summary is given here for easy reference. East Park (no longer in use) was an orthodox grass-covered enclosure at a

height of 65 ft* above mean sea level. The exposure, while fairly good for an urban site, was not ideal, the enclosure being situated on a slight mound, about 3 ft above the general level, almost completely surrounded by a thick holly hedge 4 ft 6 in high, and with trees in the surrounding park sheltering the site to some extent. At its nearest point, the holly hedge was about 16 ft distant from the thermometer screen.

The Weather Centre roof is asphalt-covered, 33 ft above street level and 61 ft above sea level, and is part of a long, nearly level roof which lies almost north–south. At the south-west corner, just off the main roof, the anemometer lattice tower rises to 16 ft with the retractable mast extending to 30 ft above the site level; about 75 yd* distant to the south-west is a large block of flats, but these are the only significant obstructions. This site and the East Park site are at almost the same height above sea level. The main differences between them are the nature of the underlying surfaces—grass and asphalt—and the more open aspect of the roof site at its height of 33 ft above street level.

The Mayflower Park site is situated directly alongside the River Test, the Park having been established on reclaimed land. The subsoil consists of miscellaneous debris and dredged material and the ground is fairly level, the height of the rain-gauge being 11 ft above mean sea level, and the base of the screen 14 ft 6 in. The enclosure is about 500 ft from the river bank (wall) to the south and separated by a hedge of evergreens (about 3 ft high) from the Docks approach road which extends along the north side of the Park. Insignificant obstructions are a children's playground 200 ft to the south-east and warehouse buildings about 300 ft to the west.

Monthly mean maximum and minimum temperatures. Dealing briefly with East Park and Weather Centre figures (not tabulated), the 1965 means confirmed Love's findings that the Park maxima were almost invariably higher than those recorded at the Weather Centre (the only exceptions being the unusually cold months of January and February 1963). They also confirm that the smallest differences are measured in the winter months. Park minima were invariably lower than those for the roof site, with the smallest differences now being measured in the summer months.

A general assessment therefore is that the diurnal range of temperature was greater at East Park than at the Weather Centre throughout the year by about one to one and a half degrees Celsius, with higher maxima in the summer and lower minima in the winter. The Mayflower–Weather Centre comparison produces results which are perhaps rather more unexpected (Tables I and II).

Annual mean maxima show virtually no difference at all between the sites. Monthly mean differences generally are 0·4 degrees or less throughout the year (apart from 0·7 in September 1972), and they fluctuate either side of zero with, on first assessment, no significant pattern. September 1972 was in fact an exceptionally cool month and the Park mean maximum of 18·0°C was the highest in the area, presumably owing to the very warm water in the nearby River Test. (Outflow from the Marchwood Power Station on the opposite bank of the river and only about one mile away results in river temperatures as high as 22°C in the summer months.)

The minimum temperature records show a slightly larger variation and Mayflower Park temperatures are generally lower, but even here the largest monthly mean difference is only 0·6 degC and the average over the three years is a mere 0·3 degC.

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* 1 ft = 0·3048 m; 1 yd = 0·9144 m.

TABLE I—MONTHLY MEAN 24-HOUR MAXIMUM TEMPERATURES

	Mayflower Park	1970 Weather Centre	Difference*	Mayflower Park	1971 Weather Centre	Difference*	Mayflower Park	1972 Weather Centre	Difference*	Three-year mean difference*	Three-year mean difference (East Park minus Weather Centre)
	°C	°C	degC	°C	°C	degC	°C	°C	degC	degC	degC
January	7·9	7·9	0·0	8·1	8·1	0·0	7·5	7·3	−0·2	−0·07	+0·13
February	7·8	7·7	+0·1	8·7	8·8	−0·1	8·3	8·1	−0·2	−0·07	+0·30
March	8·5	8·6	−0·1	9·2	9·2	0·0	12·2	12·3	−0·1	−0·07	+0·70
April	11·2	11·4	−0·2	12·8	12·8	0·0	13·4	13·3	−0·1	−0·10	+0·73
May	18·3	18·7	−0·4	17·5	17·6	−0·1	14·8	14·8	0·0	−0·17	+0·81
June	22·4	22·3	−0·1	17·8	17·7	+0·1	15·6	16·0	−0·4	−0·13	+0·73
July	20·3	20·6	−0·3	23·3	23·3	0·0	21·0	21·2	−0·1	−0·13	+0·73
August	21·3	21·6	−0·3	20·5	20·7	−0·2	21·6	21·4	+0·2	−0·10	+0·87
September	19·5	19·9	−0·4	20·7	20·6	+0·1	18·0	17·3	+0·7	+0·13	+0·77
October	15·6	15·6	0·0	16·7	17·0	−0·3	15·6	15·5	+0·1	−0·07	+0·83
November	12·5	12·6	−0·1	10·9	10·8	+0·1	10·8	10·7	+0·1	+0·03	+0·57
December	7·5	7·4	+0·1	9·5	9·5	0·0	10·0	10·1	−0·1	0	+0·40
Year	14·4	14·5	−0·1	14·6	14·7	−0·1	14·1	14·0	0·1		

* Mayflower Park values minus Weather Centre values.
The 24-hour period starts and ends at 09 GMT.

TABLE II—MONTHLY MEAN 24-HOUR MINIMUM TEMPERATURES

	Mayflower Park	1970 Weather Centre	Difference*	Mayflower Park	1971 Weather Centre	Difference*	Mayflower Park	1972 Weather Centre	Difference*	Three-year mean difference*	Three-year mean difference (East Park minus Weather Centre)
	°C	°C	*degC*	°C	°C	*degC*	°C	°C	*degC*	*degC*	*degC*
January	3·1	2·8	+0·3	3·4	3·6	−0·2	2·8	3·0	−0·2	−0·03	−0·70
February	1·8	1·4	+0·4	2·1	2·4	−0·3	3·1	3·7	−0·6	−0·17	−0·43
March	1·5	1·3	+0·2	2·5	2·9	−0·4	4·1	4·4	−0·3	−0·17	−0·70
April	4·2	4·1	+0·1	5·2	5·3	−0·1	6·2	6·7	−0·5	−0·17	−0·50
May	9·1	9·5	−0·4	8·4	8·8	−0·4	7·9	8·2	−0·3	−0·37	−0·50
June	12·8	13·0	−0·2	10·1	10·4	−0·3	9·1	9·4	−0·3	−0·27	−0·37
July	12·3	12·4	−0·1	13·7	14·2	−0·5	12·6	13·0	−0·4	−0·33	−0·47
August	13·1	13·2	−0·1	13·7	14·1	−0·4	12·1	12·5	−0·4	−0·30	−0·47
September	11·8	12·1	−0·3	10·5	11·1	−0·6	9·1	9·6	−0·5	−0·47	−0·50
October	8·4	8·0	+0·4	8·7	9·0	−0·3	8·5	8·9	−0·4	−0·10	−0·83
November	6·7	6·4	+0·3	2·9	3·4	−0·5	4·1	4·4	−0·3	−0·17	−0·73
December	2·3	2·4	−0·1	4·9	5·1	−0·2	4·7	5·0	−0·3	−0·20	−1·13
Year	7·3	7·2	+0·1	7·2	7·5	−0·3	7·0	7·4	−0·4		

* Mayflower Park values minus Weather Centre values.
The 24-hour period starts and ends at 09 GMT.

If three-year averages of the monthly mean differences of maximum and minimum temperatures are calculated, graphs of the results (Figures 2 and 3) show a distinct seasonal pattern for the East Park and Weather Centre data with the difference between the maxima increasing markedly from winter to summer, and the difference between the minima showing a noticeable decrease. On the Mayflower Park–Weather Centre graph, the effect is seen to be much less with just a slight increase in maxima differences, winter to summer, but a rather more significant increase in minima differences.

Daily differences of 24-hour maximum and minimum temperatures. These were also analysed by Love but since the 1965 figures only serve to bear out those already considered there is little point in reprinting the tables. The Fahrenheit scale of temperature was used and the results showed that about 88 per cent of roof maxima fell within the range 0·5 degF above to 2·5 degF below the East Park maxima and nearly 93 per cent of roof minima fell within the range 0·5 degF below to 2·5 degF above the East Park values.

Tables III and IV show quite clearly that an equally close agreement can be expected for the Mayflower Park and roof readings, i.e. 85 per cent of the differences between Park and roof maxima, and 91 per cent of the differences between minima fell within the range plus 0·5 degC to minus 0·9 degC. Although the mean annual and monthly comparisons showed insignificant variation between the two sites, a close study of the daily differences gives

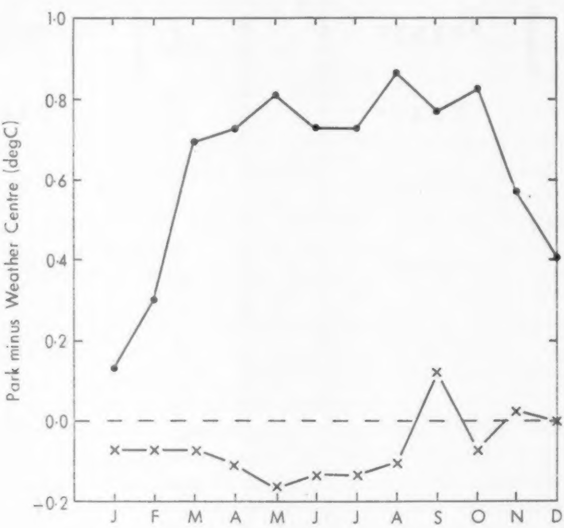

FIGURE 2—DIFFERENCE BETWEEN MONTHLY MEAN MAXIMUM TEMPERATURES RECORDED AT EAST PARK, MAYFLOWER PARK AND SOUTHAMPTON WEATHER CENTRE, 1970–72

· ——— · East Park.
X ——— X Mayflower Park.

TABLE III—MONTHLY MEANS OF DAILY DIFFERENCES OF 24-HOUR MAXIMUM TEMPERATURES, 1970–72

*Difference** *degC*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Percentage number of occasions												
More than 1·5	2	1					3	1	3		2		1·0
1·1 to 1·5	2	2	1	2		2	2	3	9	1	1		2·1
0·6 to 1·0	9	8	6	9	10	2	5	12	12	4	6	5	7·3
0·1 to 0·5	15	10	24	13	14	18	16	16	16	15	19	24	16·7
0·0 to −0·4	60	66	48	51	42	50	36	33	37	60	58	51	49·3
−0·5 to −0·9	10	10	19	23	25	22	29	26	19	19	13	16	19·3
−1·0 to −1·4	2	2	2	2	9	6	9	9	4	1	1	2	4·1
−1·5 and over		1										2	0·3

* Mayflower Park values minus Weather Centre values. The 24-hour period starts and ends at 09 GMT.

TABLE IV—MONTHLY MEANS OF DAILY DIFFERENCES OF 24-HOUR MINIMUM TEMPERATURES, 1970–72

*Difference** *degC*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Percentage number of occasions												
More than 1·5		1		1				1					
1·1 to 1·5										1		1	0·3
0·6 to 1·0		2			1	1		1		2	2	1	0·2
0·1 to 0·5	18	17	14	6	12	13	11	10	8	3	16	10	0·8
0·0 to −0·4	60	54	58	59	50	66	61	53	47	59	45	60	11·5
−0·5 to −0·9	20	19	18	25	30	17	24	32	26	24	31	23	56·0
−1·0 to −1·4	2	7	7	6	7	1	3	2	18	11	6	3	24·1
−1·5 and over			3	3		2	1	1	1			2	1·1

* Mayflower Park values minus Weather Centre values. The 24-hour period starts and ends at 09 GMT.

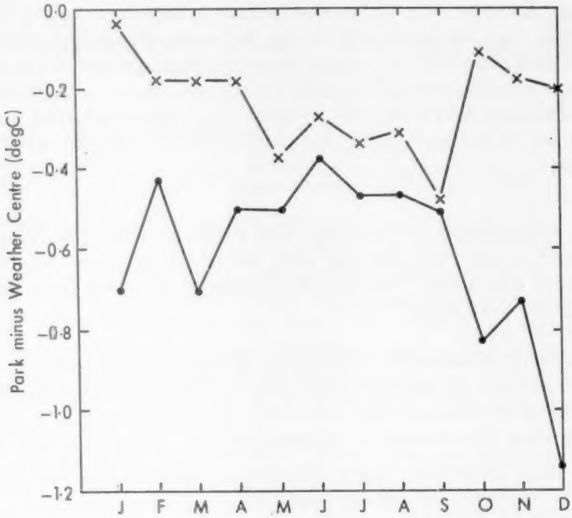

FIGURE 3—DIFFERENCE BETWEEN MONTHLY MEAN MINIMUM TEMPERATURES RECORDED AT EAST PARK, MAYFLOWER PARK AND SOUTHAMPTON WEATHER CENTRE, 1970–72

• ——— • East Park.
X ——— X Mayflower Park.

rather more positive results. The Weather Centre maxima are 0·0 to 0·4 degC higher on almost 50 per cent of occasions and between 0·5 and 0·9 degC on about 19 per cent. However, there is a clear trend for the frequency to increase in the 0·5–0·9 range, at the expense of the other, from March to August with a sudden reversal of the trend in September (Table III). That is, the roof site shows a progressive warming during the spring and high summer, relative to Mayflower Park, but cools very quickly again in September. The 'non-fit' of the month of June is almost certainly due to the fact that this was a particularly cool month in both 1971 and 1972 (maximum temperatures 2–3 degC below normal, minimum temperature 1–2 degC below), and the usual steady monthly rise of mean temperature was seriously affected.

The reasons for these seasonal changes are far from obvious. One explanation could be that the built-up area around the roof site has a warming effect, though this is not borne out by East Park figures which were generally higher than those for the roof. A more probable cause is that sea-breezes setting in during the summer months would affect the Mayflower Park site some time before the roof site and allow the latter to attain a higher maximum. Sea-breeze frequencies would be expected to decrease noticeably during September.

Minimum temperatures (Table IV). Inspection shows the very positive nature of the difference between the sites, the Weather Centre figures being equal to, or higher than, those for Mayflower Park on more than 87 per cent

of occasions. Even so, the difference is mostly less than half a degree. No definite trends can be identified except for some slight indication of more frequent occasions during the winter months (January and February in particular) when Mayflower Park minima were higher than those recorded on the roof. Observations would appear to show that these occurred on occasions when there was a southerly component to the wind, blowing directly off the 'warm' water.

Greater anomalies. An attempt was made to assess the reasons for the larger differences between the two sites, i.e. those in excess of 1 degC both maximum and minimum. No definite pattern(s) emerged from this, but the following points were noted:

(a) Some large differences of maxima (positive or negative) occurred on showery days—presumably due to the difference in intensity, distribution or time of the showers but with only one observation per day at Mayflower Park this cannot be substantiated.

(b) Some large anomalies, again both positive and negative, also occurred on days of prolonged moderate–heavy rain.

(c) Large positive differences of minima (roof higher) were noted when temperatures were rising rapidly around 09 GMT. Two observers are involved so the time difference would not be great, and the rate of rise on the roof was invariably quicker than at Mayflower Park.

Conclusions. The most interesting fact emerging from this dual analysis is that although the East Park temperatures showed a fairly close agreement with those for the Weather Centre, the Mayflower Park readings are even closer. The maximum temperatures show East Park to be warmer than the roof of the Weather Centre which is in turn warmer than Mayflower Park, whereas the minimum temperatures show East Park to be colder than Mayflower Park, which is colder than the roof.

Love argued that the closer agreement between the two sites in Southampton (East Park and the Weather Centre roof) than between those found by Marshall[2] in London is probably due to the lower height of the building above street level (33 ft against 122 ft) and the lower thermal capacity of the smaller building. As a result of the Mayflower Park comparison it would appear that the thermal capacity of the Weather Centre building has very little effect on the readings obtained (half a degree Celsius or less), and that the extreme temperatures recorded on the roof can be considered to be equally representative of the city as were those recorded on conventional sites. It is also probable that one could assume that at any given time of day the temperatures at the climatological station and on the roof would show an acceptable measure of agreement.

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2. MARSHALL, W. A. L.; London temperatures. *Met Mag, London*, **77**, 1948, pp. 54–59.

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AN INVESTIGATION INTO CONSECUTIVE WET WORKING DAYS AT SOUTHAMPTON

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Summary. The number of consecutive wet days at Southampton Weather Centre for the 10-year period 1963–72 was analysed to help in the planning of outdoor activities.

Introduction. Numerous requests are received at the Weather Centre for information on rainfall during daylight hours from the construction industries, farmers, market gardeners, sports clubs and organizers of outdoor entertainments, to assist them in planning ahead. An investigation was undertaken by H. V. Foord* using London Weather Centre data and it was considered that a similar study for a place in central southern England close to the coast and centred in one of the major urban development areas would allow for some comparison with the London data for the benefit of designers and planners in industry and commerce.

Although Southampton is at the head of Southampton Water and 10 miles or so from an imaginary line across the base of this inlet, it can be treated more or less as a coastal station as far as rain-bearing frontal systems are concerned. The majority of the most active systems approach from a south-westerly direction and Southampton has little shelter from this quarter. Rainfall data over the 24-hour period are available for Southampton for about 100 years but hyetograms only date from 1963, after the opening of the Weather Centre.

Procedure. A direct comparison with the London Weather Centre analysis was not possible. Foord used the period 1946–71, but detailed rainfall data for Southampton Weather Centre are only available from 1963, so the period used was the decade 1963–72. Also, a 'wet working day' was defined as one with one millimetre or more of rain between 06 GMT and 18 GMT. This period was necessarily selected in order to fit the rainfall readings and although it differs from the 09–18 GMT period used by Foord it probably covers more closely the working day of the construction industry over the part of the year when most work is undertaken.

Frequency of consecutive working days. The analysis of data has been prepared in the same format as Foord's to allow for some comparison. Table I shows the frequencies of single wet working days and sets of consecutive wet working days, as defined above, for each month, and the total frequencies over the 10-year period. However, in order to decide the chances of achieving dry weather on one day by allotting a certain number of consecutive days to a project, sets with a high number of consecutive wet days must be taken to contribute to the sets of lower numbers of consecutive wet days, i.e. three consecutive wet days also count as three single wet days and as two occasions of two consecutive wet days, and so on. These cumulative frequencies are given in Table II for each month, together with the total frequencies for the 10-year period. The cumulative averages are given in Table III, together with the annual averages and standard deviations and the monthly cumulative averages for the whole period.

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* FOORD, H. V.; An investigation into consecutive wet working days at London Weather Centre. *Met Mag, London*, **101**, 1972, pp. 362–366.

TABLE I—TOTALS OF CONSECUTIVE WET WORKING DAYS, JANUARY 1963 TO DECEMBER 1972

	Consecutive wet working days					
	1	2	3	4	5	6 and over
January	37	11	3	4	0	0
February	24	8	4	1	0	1
March	25	8	6	1	0	0
April	28	6	3	1	1	0
May	38	5	6	1	0	0
June	24	8	3	1	1	0
July	29	5	1	0	0	0
August	25	10	2	0	0	0
September	19	9	3	2	0	0
October	26	9	4	1	0	0
November	29	11	2	0	2	1 (8 days)
December	36	9	4	0	0	1 (8 days)
Total	340	99	41	12	4	3

TABLE II—CUMULATIVE TOTALS OF CONSECUTIVE WET WORKING DAYS, JANUARY 1963 TO DECEMBER 1972

	Consecutive wet working days					
	1	2	3	4	5	6
January	84	29	11	4	0	0
February	62	24	10	4	2	1
March	63	23	8	1	0	0
April	58	19	8	3	1	0
May	70	20	7	1	0	0
June	58	21	8	3	1	0
July	42	7	1	0	0	0
August	51	14	2	0	0	0
September	54	21	7	2	0	0
October	60	17	6	1	0	0
November	75	30	14	9	6	3
December	74	24	10	5	4	3
Total	751	249	92	33	14	7

Figure 1 shows the frequency distribution of the annual cumulative totals of single wet working days. The distribution is well scattered and not normal, as some 70 per cent of the totals are above the mean annual value.

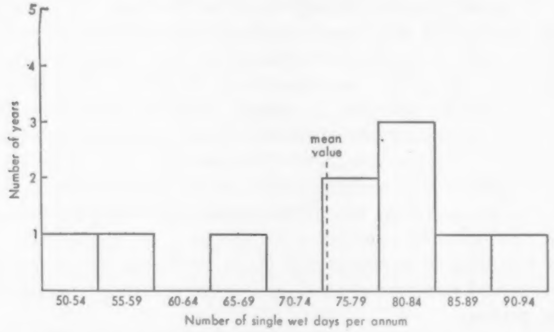

FIGURE 1—FREQUENCY DISTRIBUTION OF ANNUAL CUMULATIVE TOTALS OF SINGLE WET DAYS

Figure 2 shows the frequency distribution of the annual cumulative totals of pairs of consecutive wet working days. This shows a more even distribution, but with a high proportion concentrated in the extreme values.

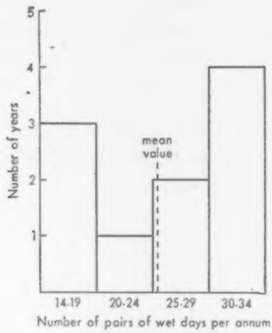

FIGURE 2—FREQUENCY DISTRIBUTION OF ANNUAL CUMULATIVE TOTALS OF PAIRS OF WET DAYS

TABLE III—CUMULATIVE AVERAGES OF CONSECUTIVE WET WORKING DAYS, JANUARY 1963 TO DECEMBER 1972

	Consecutive wet working days					
	1	2	3	4	5	6
January	8·4	2·9	1·1	0·4	0·0	0·0
February	6·2	2·4	1·0	0·4	0·2	0·1
March	6·3	2·3	0·8	0·1	0·0	0·0
April	5·8	1·9	0·8	0·3	0·1	0·0
May	7·0	2·0	0·7	0·1	0·0	0·0
June	5·8	2·1	0·8	0·3	0·1	0·0
July	4·2	0·7	0·1	0·0	0·0	0·0
August	5·1	1·4	0·2	0·0	0·0	0·0
September	5·4	2·1	0·7	0·2	0·0	0·0
October	6·0	1·6	0·6	0·1	0·0	0·0
November	7·5	3·0	1·4	0·9	0·6	0·3
December	7·4	2·4	1·0	0·5	0·4	0·3
Annual mean	75·1	24·9	9·2	3·4	1·4	0·7
Annual standard deviation	12·61	6·34	3·90	2·01	1·50	1·18
Monthly mean	6·3	2·1	0·8	0·28	0·12	0·06

Results

Average annual data. In the period under review Table III shows that there were on average:

75 wet working days in each year (lowest total 50, highest total 92) with a standard deviation of 12·6,

25 pairs of wet days in each year (lowest 14, highest 33) with a standard deviation of 6·3,

9 trios of wet days in each year (lowest 2, highest 14) with a standard deviation of 3·9,

3 quartets of wet days in each year,

1 quintet of wet days in each year,

1 sextet of wet days in seven years out of 10, but really concentrated in two unusually prolonged wet spells when two 8-day sequences occurred.

Average monthly data. Similarly there were on average, during the period under review:

6 wet working days in each month (lowest total 0, highest total 15),

2 pairs of wet days in each month (lowest 0, highest 8),

1 trio of wet days in each month,

1 quartet of wet days in every four months,

1 quintet of wet days in every nine months,

1 sextet of wet days in every 17 months.

Probabilities. For trying to complete a one-day project in dry weather (i.e. by definition less than one millimetre of rain per day) the likelihood is:

80 per cent if allotting only one day,

93 per cent if allotting two consecutive days,

97 per cent if allotting three consecutive days,

or, to put it another way, the chance of rain preventing completion is:

4 to 1 against if only one day is allotted to a task,

15 to 1 against if two consecutive days are allotted,

40 to 1 against if three consecutive days are allotted.

Discussion. There were spells of four wet working days in all but one of the 10 years examined; and two sequences of eight wet working days were recorded, one in November and the other in December of a different year.

June had eight occurrences of three consecutive wet days, whereas only one occurred in July. This rather surprising feature may be due to the relatively short period under examination. Apart from this, the cumulative totals show some increase in the period November–January, with about 20 per cent less in the spring and summer months compared with the remainder of the year (winter and autumn). July and August show a much higher proportion of single wet working days, which suggests a convective type of rainfall with the wet period probably concentrated in a short part of the working day.

In general, the longest wet spells, apart from an isolated occasion in June, are confined to the months November–April.

The cumulative averages reveal a marked increase over the equivalent values for London Weather Centre. However, taking into account the higher annual rainfall of the Southampton area, most of the monthly averages are increased by a similar ratio. The main exception is January, with almost twice the average number of wet working days, and one day out of four likely to be a wet one. Over the whole year, the odds of 6 to 1 against rain preventing completion of a one-day project in London, if allotting only a single day, are reduced to 4 to 1 for the Southampton area.

OBITUARY

It is with regret that we have to record the death of Mr. G. A. Samuel, Senior Scientific Officer, Met O 6, on 17 August 1974.

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NOTICES

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